Development and Demonstration of Shiptracking Capabilities for a Dual-Use Multi-Static Long-Range HF Radar Network

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LONG-TERM GOALS

The long-term goal is to develop a prototype dual-use HF Radar network that could be expanded to ring most of the U.S. coast and is capable of providing both real-time surface current fields and ship tracks to a variety of users.

OBJECTIVES

The immediate objective of this grant is to develop and demonstrate a ship-tracking capability for large vessels within an existing multi-static CODAR HF Radar array deployed along the New Jersey Shelf.

APPROACH

This project expands the successful partnership between Rutgers University (RU) and CODAR Ocean Sensors (COS) through the addition of Applied Mathematics, Inc. (AMI), a firm with extensive experience in the development of submarine tracking algorithms for the U.S. and British Navies. The project is divided into three major tasks to be implemented over two years.

Tasks:

1. Develop and demonstrate a ship tracking capability for multiple monostatic CODAR sites using the simpler radial geometry of the more common backscatter systems.

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14. ABSTRACT
The long-term goal is to develop a prototype dual-use HF Radar network that could be expanded to ring most of the U.S. coast and is capable of providing both real-time surface current fields and ship tracks to a variety of users.

15. SUBJECT TERMS

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2. Develop and demonstrate a ship tracking capability in a multi-static CODAR network that includes the more complicated elliptical geometry of the bistatic systems.

3. Real-time demonstration of the evolving capability in the Rutgers CODAR network.

Schedule:

Task 1 will be the focus of year 1, Task 2 will run concurrently but will extended well into year 2, and Task 3 will take place at the end of year 2.

Key Individuals:

Scott Glenn, RU, Multistatic HF Radar Array Operation
Don Barrick, COS, HF Radar Ship Detection Software Development
Bill Browning, AMI, Ship Tracking Software Development

WORK COMPLETED

All data collection efforts conducted to date are listed in Table 1. The larger vessels are the focus of this project, the smaller fast vessels are the focus of a related DoD project.

Table 1: Vessel tracking tests in Rutgers CODAR network

Detection Time Period	*Ship*	*Ship Length/Height*	*Tracked from*	*Frequency*	*Raw Data Archived & Distibuted*	*Detection Files Generated*	*Kalman Filter Solution Generated*
June 18-24,2001	Endeavor	185'/84'	Sandy Hook	5 MHz	√	√	√
June 19-23, 2001	Oleander	387'/98'	Sandy Hook	5 MHz	√	√	√
November 22-24, 2002	Oleander	387'/98'	Sandy Hook & Loveladies	5 MHz	√	√	√
December 16-19, 2002	Coast Guard Finback	82'/48'	Wildwood	5 MHz	√	√	√
March 26,2003	Sea Tow Greg	25'/13'	Tuckerton	5 MHz	√		
April 21, 2003	Sea Tow Greg	25'/13'	Tuckerton	5 MHz	√		
May 7, 2003	Rosemary Miller	95'/32'	Sandy Hook & Loveladies	5 MHz	√		
May 20, 2003	Sea Tow Mike	20'/13'	Tuckerton	5 MHz	√	√	√
July 30, 2003	Sea Tow Joe	41'/20'	Tuckerton & Loveladies	5 MHz	√		
September 3-4, 2003	RV Connecticut	70'/50'	Sandy Hook & Loveladies	5 MHz	√		
September 26-29, 2003	Royal Caribbean Serenade of the Seas	962'/13 decks	Sandy Hook	5 MHz	√		
October 7, 2003	Sea Tow Greg	25'/13'	Loveladies	5 MHz	√		
October 7, 2003	Sea Tow Greg	25'/13'	Brant Beach	25 MHz	√		
October 8, 2003	Sea Tow Greg	25'/13'	Loveladies	5 MHz	√	√	√
October 8, 2003	Sea Tow Greg	25'/13'	Brant Beach	25 MHz	√		

Data collected during the final 2001 R/V Endeavor cruise for the ONR HyCODE project provided the initial experience for development the automated programs that followed. Peaks in the Loveladies CODAR Doppler spectra associated with the R/V Endeavor were identified by eye, and detection files (range, range rate and bearing time series) were generated by hand assuming idealized antenna beam patterns for bearing. Detection data were input to a simple constant course and speed Kalman filter to generate a standard range to target solution.

Building on the Endeavor experience, a second round of tests were conducted on the larger M/V Oleander and a smaller Coast Guard Finback patrol boat in late 2002. Raw time series data were collected at each CODAR site during the tests. GPS data were logged on the Oleander by URI and on the Finback by the Coast Guard R&D Center. Receive antenna beam patterns were re-measured. Automated peak picking algorithms to identify the ship peak in the Doppler spectrum calculated from the monopole of the receive antenna were developed to provide range and range rate. Algorithm development included testing of an Infinite Impulse Response filter and a 2-D median filter to identify the noise floor. Peaks identified in the monopole along with the loop 1 and loop 2 Doppler spectra were passed through the MUSIC algorithm to estimate the bearing with both idealized and measured beam patterns. Detection files were generated for several thresholds (in dB) for the ship peak above the noise and for both idealized and real beam patterns. A constant course and speed Kalman filter that includes a statistical test for a potential maneuver to a second constant course and speed was modified to accept these detection files with error bars as the inputs. The Kalman Filter was applied to the Finback test using data from the single CODAR site at Wildwood and to the Oleander test from the two CODAR sites at Sandy Hook and Loveladies. Results from these tests are reported below.

Data collection for the next round of tests has already begun. GPS data was collected on three ships-of-opportunity, the Rosemary Miller on an NSF cruise for the Hudson River Plume, the R/V Connecticut deployment of a bistatic CODAR buoy for ONR, and a large Cruise ship leaving New York Harbor. Raw time series were collected at the Sandy Hook, Loveladies and Tuckerton CODAR sites operated in multi-static mode. The Kalman Filter has been modified to accept input detection files from a bi-static detections.

RESULTS

The R/V Endeavor initial by-eye detection and simple Kalman filter tracking solution were reported in September, 2002. This report focuses on the results from the tracking tests from the USCG Finback and the M/V Oleander. Results of the small boat tests will be reported to DoD. Other tests listed in the table are still underway.

Sample output from the automated peak-picking detection software are illustrated for the Coast Guard Finback test in Figure 1. A constant course and speed segment of the track as the vessel approached Delaware Bay was chosen for the full test. Range and range rate are based on the observed peak in the monopole. Compared to the GPS track, range rate is the most accurate, since Doppler shifts are the basic measurement made by HF Radars. Range is discretized based on the width of the frequency sweep. Tradeoffs identified in the tests indicate that smaller range cells result in less sea-clutter (dependent on cell size) to compete with the ship peak; difficulty in obtaining wide bandwidth approvals will ultimately limit this benefit. A number of radar signal pulsing formats were tested. For the same output average power, one can increase the echo signal strength in the early range cells at the expense of weaker signals and/or blind zones further out. Ultimately, interleaved pulse formats can

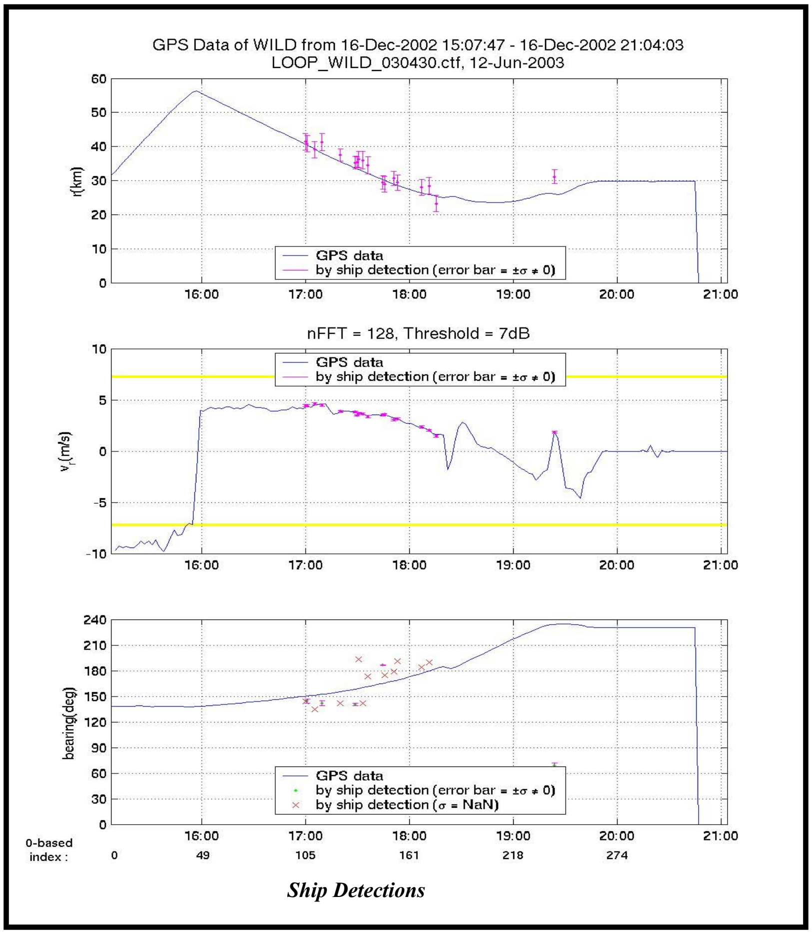

Figure 1. Sample CODAR ship detection results (range, range-rate and bearing) for the USCG Finback compared to the GPS data log.

offer the best of both of these alternatives. Bearing to target estimates exhibit the most variability about the GPS bearing. For vessels generally approaching or moving away from a site, it was found that measured beam patterns reduce biases in the approximately constant bearing. Bearing standard deviations were found to be inversely proportional to the square-root of the signal to noise ratio. One method to improve the signal to noise ratio to be tested in year 2 is to combine the data from all three antennas for the peak-picking algorithm.

The Kalman filter generates a best-fit solution of a model track to the input detection data (range, range rate and direction values and their error estimates). For the plots discussed here, the Kalman filter was run iteratively, each time adding an additional detection to generate a time series of current position estimates. The time series of current position estimates are compared to the GPS track for the Finback in Figure 2. Initially the current position data is noisey, which can be traced to the variability in the bearing. However, once a long enough time series of detections is achieved, the current position estimates lock on to the GPS track and stay locked on for the remainder of the test. This illustrates a common operational experience with Kalman filter trackers, that they are excellent trackers, once initialized.

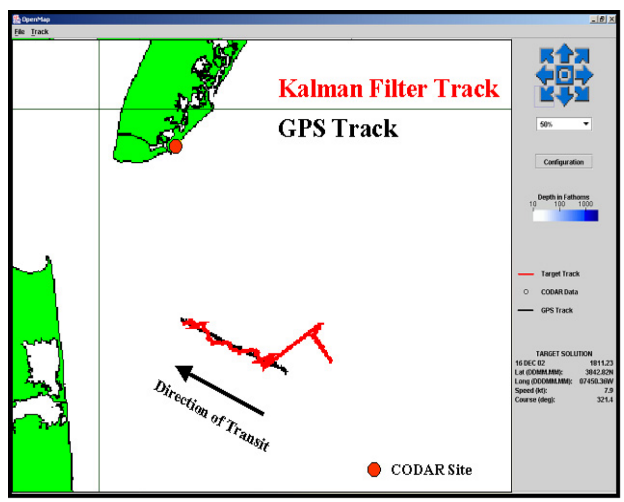

Figure 2. Time series of Kalman filter current position solutions derived from a single CODAR compared to the GPS track for the USCG Finback approaching Delaware Bay.

A similar result is illustrated in Figure 3 for the M/V Oleander as it leaves New York Harbor on a straight and steady course to Bermuda. In this case, it was tracked by both the Sandy Hook and the Loveladies CODARs. Initially it is only within view of the Sandy Hook radar, and the time series of current position estimates exhibits the same initial noise. In this case, however, as soon as the

same ship is spotted in the Loveladies radar and its detections are added to the Kalman filter, the current position solution locks right on the target. The multiple range estimates with mid-size error bars are responsible for the immediate lock on. As before, once the Kalman filter is locked on the track, it does an excellent job of maintaining the track, even after reverting back to single radar coverage near the end of the test.

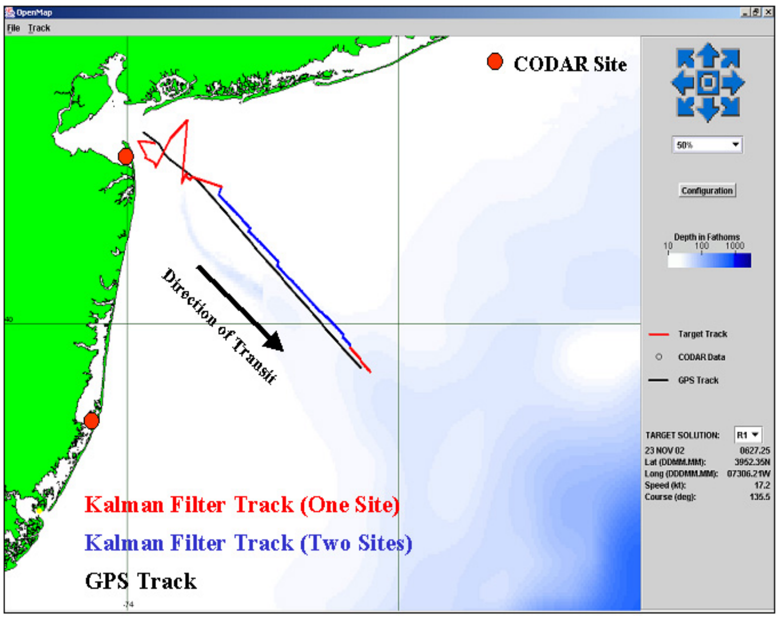

Figure 3. Time series of Kalman filter current position solutions derived from two CODARs compared to the GPS track for the M/V Oleander exiting New York Harbor.

IMPACT/APPLICATIONS

The International Ocean Observing System (IOOS) Surface Current Initiative (SCI) has formed a steering committee to facilitate the implementation of a national HF Radar backbone that will consist of approximately 100-150 HF Radar sites deployed along the U.S. coasts including Alaska and Hawaii. The mature ocean current mapping capability and developing shiptracking capability of CODAR HF Radars make it an attractive candidate technology for this network.

The Norwegian government is now being briefed on CODAR ship-tracking capabilities. Their specific interest is to track large oil tankers transiting along their coast and to acquire real-time surface current maps in the event of an oil spill.

TRANSITIONS

Coast Guard R&D Center has completed an initial investigation of CODAR for Search and Rescue applications. Tests conducted this past year in the Rutgers and UConn networks indicate that CODAR environmental data provided a vast improvement over present Coast Guard methodology that uses buoy data. Follow-on work will include an operational evaluation of CODAR in the Middle Atlantic Region.

RELATED PROJECTS

This project makes use of the multistatic long-range CODAR array developed by the ONR-sponsored project entitled "Development and Demonstration of Bistatic and Long-Range CODAR SeaSonde HF-Radar Systems". The Coast Guard R&D center has placed a GPS logging device on one of their operational vessels for tracking tests. The Department of Defense Counterdrug Technology Development Office has funded a parallel effort to determine if small fast boats can be tracked using the same CODAR technology. These tests will include use of the SIFTER detection algorithm

developed by Mission Research Corporation that may be capable of identifying a ship peak located within the ocean wave Bragg peak.

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